MANDATORY APPENDIX XIII
DESIGN BASED ON STRESS ANALYSIS

ARTICLE XIII-1000
GENERAL REQUIREMENTS

XIII-1100 SCOPE

This Appendix is applicable for the design of metallic items when specifically permitted by the applicable Section III Subsection. This Appendix uses Division 1 terminology. When this Appendix is referenced by other divisions, (a) through (c) are applicable.

(a) The terms Service Loadings versus Operating Loadings, vessel versus containment, pressure boundary versus containment boundary, etc. shall be considered as identical in the application of these rules for Division 3 components.

(b) The stress limits for Class 1 components are also applicable for Division 5, Class A components.

(c) The stress limits for Class 2 components are also applicable for Division 5, Class B components.

XIII-1200 DESIGN ACCEPTABILITY

XIII-1210 REQUIREMENTS FOR DESIGN ACCEPTABILITY

The requirements for the acceptability of a design are as follows:

(a) The design shall be such that the stresses shall not exceed the limits described in this Appendix.

(b) For configurations where compressive stresses occur, in addition to the requirement in (a), the critical buckling stress shall be taken into account.

(c) The requirements for material, design, fabrication, examination, and testing of the applicable Subsection shall be met.

XIII-1220 BASIS FOR DETERMINING STRESSES

The theory of failure used in the rules of this Appendix is the maximum shear stress theory. The maximum shear stress at a point is equal to one-half the difference between the algebraically largest and the algebraically smallest of the three principal stresses at the point.

XIII-1300 TERMS RELATING TO STRESS ANALYSIS

Terms used in this Appendix relating to stress analysis are defined in (a) through (ak) below.

(a) Bending Stress. Bending stress is the component of normal stress that varies across the thickness. The variation may or may not be linear. The bending component of primary stress for piping is the stress proportional to the distance from the centroid of the pipe cross section.

(b) Collapse Load — Lower Bound. If, for a given load, any system of stresses can be found that everywhere satisfies equilibrium, and nowhere exceeds the material yield strength, the load is at or below the collapse load. This is the lower bound theorem of limit analysis, which permits calculations of a lower bound to the collapse load.

(c) Creep. Creep is the special case of inelasticity that relates to the stress-induced, time-dependent deformation under load. Small time-dependent deformations may occur after the removal of all applied loads.

(d) Deformation. Deformation of a component part is an alteration of its shape or size.

(e) Equivalent Linear Stress. Equivalent linear stress is defined as the linear stress distribution that has the same net bending moment and net force as the actual stress distribution.

(f) Expansion Stresses. Expansion stresses are those stresses resulting from restraint of free end displacement of the piping system.

(g) Fatigue Strength Reduction Factor. Fatigue strength reduction factor is a stress intensification factor that accounts for the effect of a local structural discontinuity (stress concentration) on the fatigue strength. Values for some specific cases, based on experiment, are given in the applicable Subsection. A theoretical stress concentration factor or stress index may be used. A fatigue strength reduction factor or stress index may also be determined using the procedures in Mandatory Appendix II.

(h) Free End Displacement. Free end displacement consists of the relative motions that would occur between a fixed attachment and connected piping if the two members were separated and permitted to move.
(i) Gross Structural Discontinuity. Gross structural discontinuity is a geometric or material discontinuity that affects the stress or strain distribution through the entire wall thickness. Gross discontinuity-type stresses are those portions of the actual stress distributions that produce net bending and membrane force resultants when integrated through the wall thickness. Examples of a gross structural discontinuity are head-to-shell junctions, flange-to-shell junctions, nozzles, and junctions between shells of different diameters or thicknesses.

(j) Inelasticity. Inelasticity is a general characteristic of material behavior in which the material does not return to its original shape and size after removal of all applied loads. Plasticity and creep are special cases of inelasticity.

(k) Limit Analysis. Limit analysis is a special case of plastic analysis in which the material is assumed to be ideally plastic (non-strain-hardening). In limit analysis, the equilibrium and flow characteristics at the limit state are used to calculate the collapse load. The two bounding methods used in limit analysis are the lower bound approach, which is associated with a statically admissible stress field, and the upper bound approach, which is associated with a kinematically admissible velocity field. For beams and frames, the term mechanism is commonly used in lieu of kinematically admissible velocity field.

(l) Limit Analysis — Collapse Load. The methods of limit analysis are used to compute the maximum load that a structure assumed to be made of ideally plastic material can carry. At this load, which is termed the collapse load, the deformations of the structure increase without bound.

(m) Load-Controlled Stress. Load-controlled stress is the stress resulting from application of a loading, such as internal pressure, inertial loads, or gravity, whose magnitude is not reduced as a result of displacement.

(n) Local Primary Membrane Stress. Cases arise in which a membrane stress produced by pressure or other mechanical loading and associated with a discontinuity would, if not limited, produce excessive distortion in the transfer of load to other portions of the structure. Conservation requires that such a stress be classified as a local primary membrane stress even though it has some characteristics of a secondary stress.

A stressed region may be considered local if the distance over which the membrane stress intensity exceeds 1.1$S_m$ (see XIII-2200) does not extend in the meridional (longitudinal) direction more than 1.0$\sqrt{R_1}$, where $R$ is the minimum midsurface radius of curvature and $t$ is the minimum thickness in the region considered. Regions of local primary stress intensity involving axisymmetric membrane stress distributions that exceed 1.1$S_m$ shall not be closer in the meridional (longitudinal) direction than $2.5\sqrt{R_1}t$, where $R_L$ is defined as $(R_1 + R_2)/2$ and $t_L$ is defined as $(t_1 + t_2)/2$ (where $t_1$ and $t_2$ are the minimum thicknesses at each of the regions considered, and $R_1$ and $R_2$ are the minimum midsurface radii of curvature at these regions where the membrane stress intensity exceeds 1.1$S_m$). Discrete regions of local primary membrane stress intensity, such as those resulting from concentrated loads acting on brackets, where the membrane stress intensity exceeds 1.1$S_m$, shall be spaced so that there is no overlapping of the areas in which the membrane stress intensity exceeds 1.1$S_m$.

Examples of local primary membrane stress include

1. membrane stress in a shell produced locally by an external load
2. membrane stress in a shell at a permanent support or nozzle location
3. circumferential membrane stress at the intersection of a cylindrical shell with a conical shell due to internal pressure, as illustrated in Figure XIII-1300-1

Local stressed area may also include areas of local wall thinning. The requirements of XIII-3770 shall be applied for these cases.

(a) Local Structural Discontinuity. Local structural discontinuity is a geometric or material discontinuity that affects the stress or strain distribution through a fractional part of the wall thickness. The stress distribution associated with a local discontinuity causes only very localized deformation or strain and has no significant effect on the shell-type discontinuity deformations. Examples are small fillet radii, small attachments, and partial penetration welds.

(b) Membrane Stress. Membrane stress is the component of normal stress that is uniformly distributed and equal to the average stress across the thickness of the section under consideration.

(c) Nonreversing Dynamic Loads. Nonreversing dynamic loads (see Figure XIII-1300-2) are those loads that do not cycle about a mean value; examples include the initial thrust force due to sudden opening or closure of valves and waterhammer resulting from entrapped water in two phase flow systems. Reflected waves in a piping system due to flow transients are classified as nonreversing dynamic loads.

(d) Normal Stress. Normal stress is the component of stress normal to the plane of reference. This is also referred to as direct stress. Usually the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to have two components, one uniformly distributed and equal to the average stress across the thickness under consideration, and the other varying from this average value across the thickness.
(s) **Peak Stress.** Peak stress is that increment of stress that is additive to the primary plus secondary stresses by reason of local discontinuities or local thermal stress [see (aj)(2)] including the effects, if any, of stress concentrations. The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture. A stress that is not highly localized falls into this category if it is of a type that cannot cause noticeable distortion. Examples of peak stress are:

1. the thermal stress in the austenite steel cladding of a carbon steel part
2. certain thermal stresses that may cause fatigue but not distortion
3. the stress at a local structural discontinuity
4. surface stresses produced by thermal shock

(b) **Plastic Analysis.** Plastic analysis is that method that computes the structural behavior under given loads considering the plasticity characteristics of the materials, including strain hardening and the stress redistribution occurring in the structure.

(u) **Plastic Analysis — Collapse Load.** A plastic analysis may be used to determine the collapse load for a given combination of loads on a given structure. The following criterion for determination of the collapse load shall be used. A load–deflection or load–strain curve is plotted with load as the ordinate and deflection or strain as the abscissa. The angle that the linear part of the load–deflection or load–strain curve makes with the ordinate is called \( \theta \). A second straight line, hereafter called the collapse limit line, is drawn through the origin so that it makes an angle \( \phi = \tan^{-1} (2 \tan \theta) \) with the ordinate. The collapse load is the load at the intersection of the load–deflection or load–strain curve and the collapse limit line (see Figure II-1430-1). If this method is used, particular care should be taken to ensure that the strains or deflections that are used are indicative of the load-carrying capacity of the structure.

(v) **Plastic Hinge.** A plastic hinge is an idealized concept used in Limit Analysis. In a beam or a frame, a plastic hinge is formed at the point where the moment, shear, and axial force lie on the yield interaction surface. In plates and shells, a plastic hinge is formed where the general membrane stresses lie on the yield surface.

(w) **Plastic Instability Load.** The plastic instability load for members under predominantly tensile or compressive loading is defined as that load at which unbound plastic deformation can occur without an increase in load. At the plastic tensile instability load, the true stress in the material increases faster than strain hardening can accommodate.

(x) **Plasticity.** Plasticity is the special case of inelasticity in which the material undergoes time-independent non-recoverable deformation.

(y) **Primary Stress.** Primary stress is any normal stress or shear stress developed by an imposed loading that is necessary to satisfy the laws of equilibrium of external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses that considerably exceed the yield strength will result in failure or, at least, in gross distortion. Primary membrane stress is divided into general and local categories. A general primary membrane stress is one that is so distributed in the structure that no redistribution of load occurs as a result of yielding. Examples of primary stress are:

1. general membrane stress in a circular cylindrical shell or a spherical shell due to internal pressure or to distributed loads
2. bending stress in the central portion of a flat head due to pressure

Refer to Table XIII-2600-1 for examples of primary stress.

(z) **Ratcheting.** Ratcheting is a progressive incremental inelastic deformation or strain that can occur in a component subjected to variations of mechanical stress, thermal stress, or both.

(aa) **Reversing Dynamic Loads.** Reversing dynamic loads (see Figure XIII-1300-2) are those loads that cycle about an arbitrary mean value; examples include building filtered and earthquake loads.

(ab) **Secondary Stress.** Secondary stress is a normal stress or a shear stress developed by the constraint of adjacent material or by self-constraint of the structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions that cause the stress to occur and failure from one application of the stress is not to be expected. Examples of secondary stress are:

1. general thermal stress [see (aj)(1)]
2. bending stress at a gross structural discontinuity

Refer to Table XIII-2600-1 for examples of secondary stress.

(ac) **Service Cycle.** Service cycle is defined as the initiation and establishment of new conditions followed by a return to the conditions that prevailed at the beginning of the cycle.

(ad) **Shakedown.** Shakedown of a structure occurs if, after a few cycles of load application, ratcheting ceases. The subsequent structural response is elastic, or elastic–plastic, and progressive incremental inelastic deformation is absent. Elastic shakedown is the case in which the subsequent response is elastic.

(ae) **Shear Stress.** Shear stress is the component of stress tangent to the plane of reference.

(af) **Strain-Limiting Load.** When a limit is placed upon a strain, the load associated with the strain limit is called the strain limiting load.

(ah) **Stress Cycle.** Stress cycle is a condition in which the alternating stress difference [see XIII-3520] goes from an initial value through an algebraic maximum value and an algebraic minimum value and then returns to the initial
value. A single service cycle may result in one or more stress cycles. Dynamic effects shall also be considered as stress cycles.

(ah) Stress Intensity. Stress intensity is defined as twice the maximum shear stress, which is the difference between the algebraically largest principal stress and the algebraically smallest principal stress at a given point. Tensile stresses are considered positive, and compressive stresses are considered negative. This definition of stress intensity is not related to the definition of stress intensity applied in the field of fracture mechanics.

(ai) Test Collapse Load. Test collapse load is the collapse load determined by tests according to the criteria given in II-1430.

(aj) Thermal Stress. Thermal stress is a self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally would under a change in temperature. For the purpose of establishing allowable stresses, two types of thermal stress are recognized, depending on the volume or area in which distortion takes place, as described in (1) and (2) below.

(1) General thermal stress is associated with distortion of the structure in which it occurs. If a stress of this type, neglecting stress concentrations, exceeds twice the yield strength of the material, the elastic analysis may be invalid and successive thermal cycles may produce incremental distortion. Therefore this type is classified as secondary stress in Table XIII-2600-1. Examples of general thermal stress are

(-a) stress produced by an axial temperature distribution in a cylindrical shell
(-b) stress produced by the temperature difference between a nozzle and the shell to which it is attached
(-c) the equivalent linear stress produced by the radial temperature distribution in a cylindrical shell

(2) Local thermal stress is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses shall be considered only from the fatigue standpoint and are therefore classified as peak stresses in Table XIII-2600-1. In evaluating local thermal stresses the procedures of XIII-2500(b) shall be used. Examples of local thermal stress are

(-a) the stress in a small hot spot in a vessel wall
(-b) the difference between the actual stress and the equivalent linear stress resulting from a radial temperature distribution in a cylindrical shell
(-c) the thermal stress in a cladding material that has a coefficient of expansion different from that of the base metal

(ak) Total Stress. Total stress is the sum of the primary, secondary, and peak stress contributions. Recognition of each of the individual contributions is essential to establishment of appropriate stress limitations.
ARTICLE XIII-2000
STRESS ANALYSIS

XIII-2100  OVERVIEW

(a) A detailed stress analysis of all major structural components shall be prepared in sufficient detail to show that each of the stress limits of Articles XIII-3000 and XIII-4000 is satisfied when the component is subjected to the loadings defined in the Design Specification. As an aid to the evaluation of these stresses, equations and methods for the solution of certain recurring problems have been placed in Nonmandatory Appendix A. The stress index values provided in NB-3338 may also be used for openings designed in accordance with NC-3230 or WC-3230, and NC-3259 or WC-3259.

(b) The loadings to be considered are those defined in the Design Specification and include Design Loadings, Service Loadings, and Test Loadings. The Service Loadings may be the result of the service conditions defined in the Design Specification. The Design Specification designates a Service Limit for each service condition or loading. These Service Limits are identified as Level A, Level B, Level C, and Level D. Acceptance limits are defined in this Appendix for Design Loadings, each Service Level, and Test Loadings.

(c) The stress limits also differ depending on the stress classification (primary, secondary, etc.) from which the stress is derived. The six stress classifications are identified in XIII-2300, and are distinct and separate from each other, even though all may exist at the same point. Detailed stress analyses often produce results that are a combination of these classifications and it is necessary to separate each in order to properly compare to the applicable stress limits. Subarticle XIII-2600 provides guidance for selecting the appropriate stress classification. As an example, the stresses in classification Q are those parts of the total stress that are produced by thermal gradients, structural discontinuities, etc., and they do not include primary stresses that may also exist at the same point. A detailed stress analysis frequently gives the combination of primary and secondary stresses directly and, when appropriate, this calculated value represents the total of \( P_m + P_b + Q \), and not \( Q \) alone. Similarly, if the stress in classification \( F \) is produced by a stress concentration, the quantity \( F \) is the additional stress produced by the notch over and above the nominal stress. However, \( P_L \) is the total membrane stress that results from pressure and mechanical loads, including gross structural discontinuity effects, rather than a stress increment. Therefore, the \( P_L \) value always includes the \( P_m \) contribution.

(d) The combining of classified stresses for comparison to specified limits is illustrated in Figure XIII-2100-1. The solid lines illustrate the combination of the primary stresses due to the specified load combinations for comparison to the primary stress intensity limits defined for Design Loadings, and loadings for which Level A, Level B, Level C, or Level D Service Limits are specified. At each rectangular box, the applicable sets of the six stress components for each load combination are combined to calculate the maximum stress intensity (see XIII-2300), represented by the adjacent circle. The dashed lines identify the combinations of primary, secondary, and peak stress used to evaluate the combined effects of all the loadings for which Level A and B Service Limits are specified. In this case the rectangular boxes represent the sets of the six stress components to be evaluated to determine the maximum range of the stress differences over the life of the component (see XIII-2400) for comparison to the specified limits and to determine the cumulative fatigue life of the component.

XIII-2200  DESIGN STRESS VALUES AND MATERIAL PROPERTIES

The stress intensity limits are defined in terms of the design stress intensity and yield strength. The design stress intensity values \( S_m \), are given in Section II, Part D, Subpart 1, Tables 2A and 2B for component materials and Table 4 for bolting materials. Values of yield strength, \( S_y \), are given in Section II, Part D, Subpart 1, Table Y-1. The design stress intensity and yield strength are tabulated at various temperatures. Values of the coefficient of thermal expansion and modulus of elasticity are in Section II, Part D, Subpart 2, Tables TE and TM. For all material properties, values at intermediate temperatures may be found by interpolation. The basis for establishing design stress intensity values is given in Mandatory Appendix III. The design fatigue curves used in conjunction with XIII-3500 are those in Mandatory Appendix I.

XIII-2300  DERIVATION OF STRESS INTENSITIES

This subarticle outlines the procedure for the calculation of the stress intensities that are subject to the specified limits. The steps in the procedure are stipulated below. Membrane stress is derived from the stress
components averaged across the thickness of the section. The averaging shall be performed at the component level in Step 2 or Step 3.

Step 1. At the point on the component being investigated, choose an orthogonal set of coordinates, such as tangential, meridional/longitudinal, and radial, and designate them by the subscripts $t$, $l$, and $r$. Then designate the stress components in these directions as $\sigma_t$, $\sigma_l$, and $\sigma_r$ for direct stresses and $\tau_{tl}$, $\tau_{lr}$, and $\tau_{rt}$ for shear stresses.

Step 2. Calculate the stress components for each load combination to which the part will be subjected, and assign each set of six stress components to one or a group of the following classifications. Subarticle XIII-2600 provides guidance for selecting the appropriate stress classification.

(a) general primary membrane stress, $P_m$ [XIII-1300(p) and XIII-1300(y)]
(b) local primary membrane stress, $P_L$ [XIII-1300(n)]
(c) primary bending stress, $P_b$ [XIII-1300(a) and XIII-1300(y)]
(d) expansion stress, $P_e$ [XIII-1300(f)], applicable only to piping
(e) secondary stress, $Q$ [XIII-1300(ab)]
(f) peak stress, $F$ [XIII-1300(s)]

Step 3. For each classification, calculate the algebraic sum of the $\sigma$ values that result from the different types of loadings and do the same for the other five stress components.
Step 4. Translate the stress components for the \( t, l, \) and \( r \) directions into principal stresses \( \sigma_1, \sigma_2, \) and \( \sigma_3. \) In many pressure component calculations, the \( t, l, \) and \( r \) directions may be so chosen that the shear stress components are zero and \( \sigma_1, \sigma_2, \) and \( \sigma_3 \) are identical to \( \sigma_t, \sigma_l, \) and \( \sigma_r. \)

Step 5. Calculate the stress differences \( S_{12}, S_{23}, \) and \( S_{31} \) from the following relations:

\[
S_{12} = \sigma_1 - \sigma_2 \\
S_{23} = \sigma_2 - \sigma_3 \\
S_{31} = \sigma_3 - \sigma_1 
\]

The stress intensity, \( S, \) is the largest absolute value of \( S_{12}, S_{23}, \) and \( S_{31}. \)

### XIII-2400 Derivation of Stress Differences for Evaluation of Cyclic Operation

The evaluation of the primary plus secondary stresses, the expansion stress in piping and the primary plus secondary plus peak stresses requires the calculation of the cyclic stress ranges due to the loadings for which Level A and Level B Service Limits are specified. The determination of the stress ranges shall be made on the basis of the stresses at a point on the component using the process defined in XIII-2410 or XIII-2420. If the specified operation of the component does not meet the conditions of XIII-3510, the ability of the component to withstand the specified cyclic service without fatigue failure, shall be determined as provided in XIII-3520. Only the stress differences due to cyclic Level A and Level B loadings as specified in the Design Specification need be considered.

### XIII-2410 Constant Principal Stress Direction

For any case in which the directions of the principal stresses at the point being considered do not change during the cycle, the steps stipulated below shall be taken to determine the alternating stress intensity.

Step 1. Principal Stresses. Consider the values of the three principal stresses, \( \sigma_1, \sigma_2, \) and \( \sigma_3, \) at the point being investigated versus time for the complete stress cycle, taking into account both the applicable gross and local structural discontinuities, and the thermal effects that vary during the cycle.

Step 2. Stress Differences. Determine the stress differences \( S_{12} = \sigma_1 - \sigma_2, S_{23} = \sigma_2 - \sigma_3, \) and \( S_{31} = \sigma_3 - \sigma_1 \) versus time for the complete cycle. In Step 3, the symbol \( S_{ij} \) is used to represent any one of these three stress differences.

Step 3. Alternating Stress Intensity. Determine the extremes of the range through which each stress difference, \( S_{1j}, \) fluctuates and find the absolute magnitude of this range for each \( S_{ij}. \) Call this magnitude \( S_{rij} \) and let \( S_{alt} \rightarrow 0.55 S_{rij}. \) The stress intensity range, \( S_r, \) for the stress cycle is the largest \( S_{rij}. \) The alternating stress intensity, \( S_{alt}, \) is the largest \( S_{alt} \rightarrow 0.55 S_{rij} \) value.

### XIII-2420 Varying Principal Stress Direction

For any case in which the directions of the principal stresses at the point being considered do change during the stress cycle, it is necessary to use the more general procedure described below.

Step 1. Consider the values of the six stress components \( \sigma_t, \sigma_r, \tau_{lt}, \tau_{tr}, \) versus time for the complete stress cycle, taking into account both the applicable gross and local structural discontinuities, and the thermal effects that vary during the cycle.

Step 2. Choose a point in time when the conditions are one of the extremes for the cycle (either maximum or minimum, algebraically) and identify the stress components at this time by the subscript \( i. \) In most cases, it will be possible to choose at least one time during the cycle when the conditions are known to be extreme. In some cases, it may be necessary to try different points in time to find the one that results in the largest value of alternating stress intensity.

Step 3. Subtract each of the six stress components, \( \sigma_{1i}, \sigma_{2i}, \) etc., from the corresponding stress components, \( \sigma_t, \sigma_r, \) etc., at each point in time during the cycle and call the resulting components \( \sigma_i', \sigma_r', \) etc. Note that the directions of the principal stresses may change during the cycle but each principal stress retains its identity as it rotates.

Step 4. At each point in time during the cycle, calculate the principal stresses, \( \sigma_1', \sigma_2', \) and \( \sigma_3', \) derived from the six stress components, \( \sigma_i', \sigma_r', \) etc. Note that the directions of the principal stresses may change during the cycle but each principal stress retains its identity as it rotates.

Step 5. Determine the stress differences, \( S_{12}' = \sigma_{11}' - \sigma_{21}', S_{23}' = \sigma_{21}' - \sigma_{31}', \) and \( S_{31}' = \sigma_{31}' - \sigma_{11}', \) versus time for the complete cycle. The largest absolute magnitude of any stress difference at any time is the stress intensity range, \( S_r. \) The alternating stress intensity, \( S_{alt}, \) is one-half of this magnitude.

### XIII-2500 Applications of Elastic Analysis for Stresses Beyond the Yield Strength

Certain of the allowable stresses permitted in the design criteria are such that the maximum stress calculated on an elastic basis may exceed the yield strength of the material. The limit on primary plus secondary stress intensity of \( 3S_m \) (see XIII-3420) has been placed at a level that ensures shakedown to elastic action after a few repetitions of the stress cycle except in regions containing significant local structural discontinuities or local thermal stresses. These last two factors are considered only in the performance of a fatigue evaluation. Therefore
ARTICLE XIII-3000
STRESS LIMITS FOR OTHER THAN BOLTS

XIII-3100 PRIMARY STRESS INTENSITY LIMITS

(a) Design Loadings. The stress intensity limits that are to be satisfied at the Design Temperature for the Design Loadings stated in the Design Specification are given in XIII-3110 through XIII-3130.

(b) Level A, Level B, Level C, and Level D Service Limits. The primary stress intensity limits that must be satisfied at the coincident material temperature for any Level A, Level B, Level C, or Level D loadings stated in the Design Specification are those given in XIII-3110 through XIII-3130. For piping, additional requirements are provided in XIII-3140.

(c) Testing Limits. XIII-3600 includes primary stress intensity limits for testing.

(d) The provisions of XIII-3200 may provide relief from certain of these stress limits if plastic analysis techniques are applied.

XIII-3110 GENERAL PRIMARY MEMBRANE STRESS INTENSITY

This stress intensity is derived from $P_m$ in Figure XIII-2100-1 and is calculated using the average value across the thickness of a section of the general primary stresses [see XIII-1300(y)] produced by

(a) Design Pressure and other specified Design Mechanical Loads

(b) coincident pressure and mechanical loads associated with the Service or Operating Loadings specified in the Design Specification, but excluding all secondary and peak stresses.

Averaging is to be applied to the stress components prior to determination of the stress intensity values. The allowable values of this stress intensity are tabulated in Table XIII-3110-1.

XIII-3120 LOCAL PRIMARY MEMBRANE STRESS INTENSITY

This stress intensity is derived from $P_L$ in Figure XIII-2100-1 and is calculated using the average value across the thickness of a section of the local primary stresses [see XIII-1300(n)] produced by

(a) Design Pressure and other specified Design Mechanical Loads

(b) coincident pressure and mechanical loads associated with the Service or Operating Loadings specified in the Design Specification, but excluding all secondary and peak stresses.

Averaging is to be applied to the stress components prior to determination of the stress intensity values. For piping, averaging is done across the entire pipe cross section. The allowable values of this stress intensity are tabulated in Table XIII-3110-1.

XIII-3130 PRIMARY MEMBRANE (GENERAL OR LOCAL) PLUS PRIMARY BENDING STRESS INTENSITY

This stress intensity is derived from $(P_m + P_L)$ in Figure XIII-2100-1 and is calculated using the highest value across the thickness of a section of the general or local primary membrane stresses plus primary bending stresses produced by

(a) Design Pressure and other specified Design Mechanical Loads

(b) coincident pressure and mechanical loads associated with the Service or Operating Loadings specified in the Design Specification, but excluding all secondary and peak stresses.

For solid rectangular sections, the allowable values of this stress intensity are tabulated in Table XIII-3110-1. For other than solid rectangular sections, a value of $\alpha$ times the limit on $P_m$ established in Table XIII-3110-1 may be used, where the factor $\alpha$ is defined as the ratio of the load set producing a fully plastic section to the load set producing initial yielding in the extreme fibers of the section. In the evaluation of the initial yield and fully plastic section capacities, the ratios of each individual load in the respective load set to each other load in that load set shall be the same as the respective ratios of the individual loads in the specified Design Load set. The value of $\alpha$ shall not exceed the value calculated for bending only ($P_m = 0$).

In no case shall the value of $\alpha$ exceed 1.5. The $\alpha$ factor is not permitted for Level D Service Limits when inelastic component analysis is used as permitted in Mandatory Appendix XXVII. The propensity for buckling of the part of the section that is in compression shall be investigated.

For piping, primary bending stress is proportional to the distance from the centroid of the pipe cross section.

XIII-3140 PRIMARY STRESS LIMITS FOR PIPING

For Class 1 piping components operating within the temperature limits of the applicable Subsection, the requirements of XIII-3141 through XIII-3144 shall apply.